International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:12, 2014

In-situ Observations Using SEM-EBSD for Bending Deformation in Single-Crystal Materials

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Abstract**—**To elucidate the material characteristics of single crystals of pure aluminum and copper, the respective relations between crystallographic orientations and microstructures were examined, along with bending and mechanical properties. The texture distribution was also analysed. Bending tests were performed in a SEM apparatus while its behaviors were observed. Some analytical results related to crystal direction maps, inverse pole figures, and textures were obtained from electron backscatter diffraction (EBSD) analyses.

Keywords**—**Pure aluminum, Pure copper, Single crystal, Bending, SEM-EBSD analysis, Texture, Microstructure.

I. Introduction

When pure aluminum is bent, a crack occurs in the range of bend. Crystal orientation and strength of the material cause the cracking [1]. Recent studies have shown improved processability of Cube orientation ({001}<100>) with bending [2]. It is possible to reduce the crack when the volume fraction of the Cube orientation is high [3], [4]. But it is not known in detail to what effect while processing a Cube orientation remain unclear.

Therefore, bending of pure aluminum single-crystal material was investigated to assess the rotation mechanism effects on the Cube orientation when changing the bending angle. For the single-crystal material, the crystal grain and crystal orientation need not to be considered around the crystal. This study is a simple observation of one crystal.

At the initial stage, bending deformation of the single crystal material is observed at each angle using Scanning Electron Microscope, Electron Backscatter Diffraction (SEM-EBSD). Results obtained for a single-crystal material of the same pure copper [5] (f.c.c. : face centered cubic) were compared.

II. Specimen and Experimental Method

Dimensions and directions of the bending specimen are presented in Fig. 1. Single crystals of pure aluminum and pure copper were selected as bending specimens in this study. These specimens were cut with a wire-cutting electric discharge machine: thickness t=1.0mm, width d=5.0mm, and length l=30mm.

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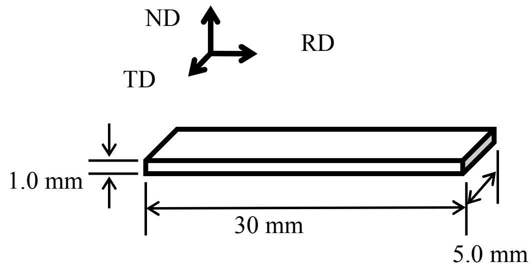
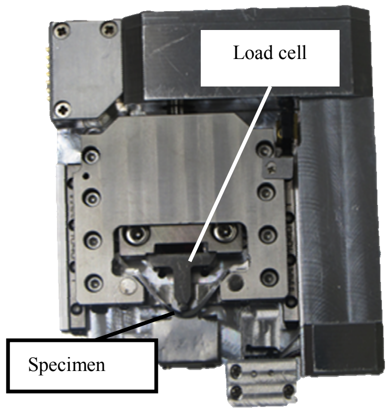


Fig. 1 Dimensions and directions of bending specimen



(a) Bending device

(b) Overview of SEM apparatus

Fig. 2 SEM-EBSD apparatus

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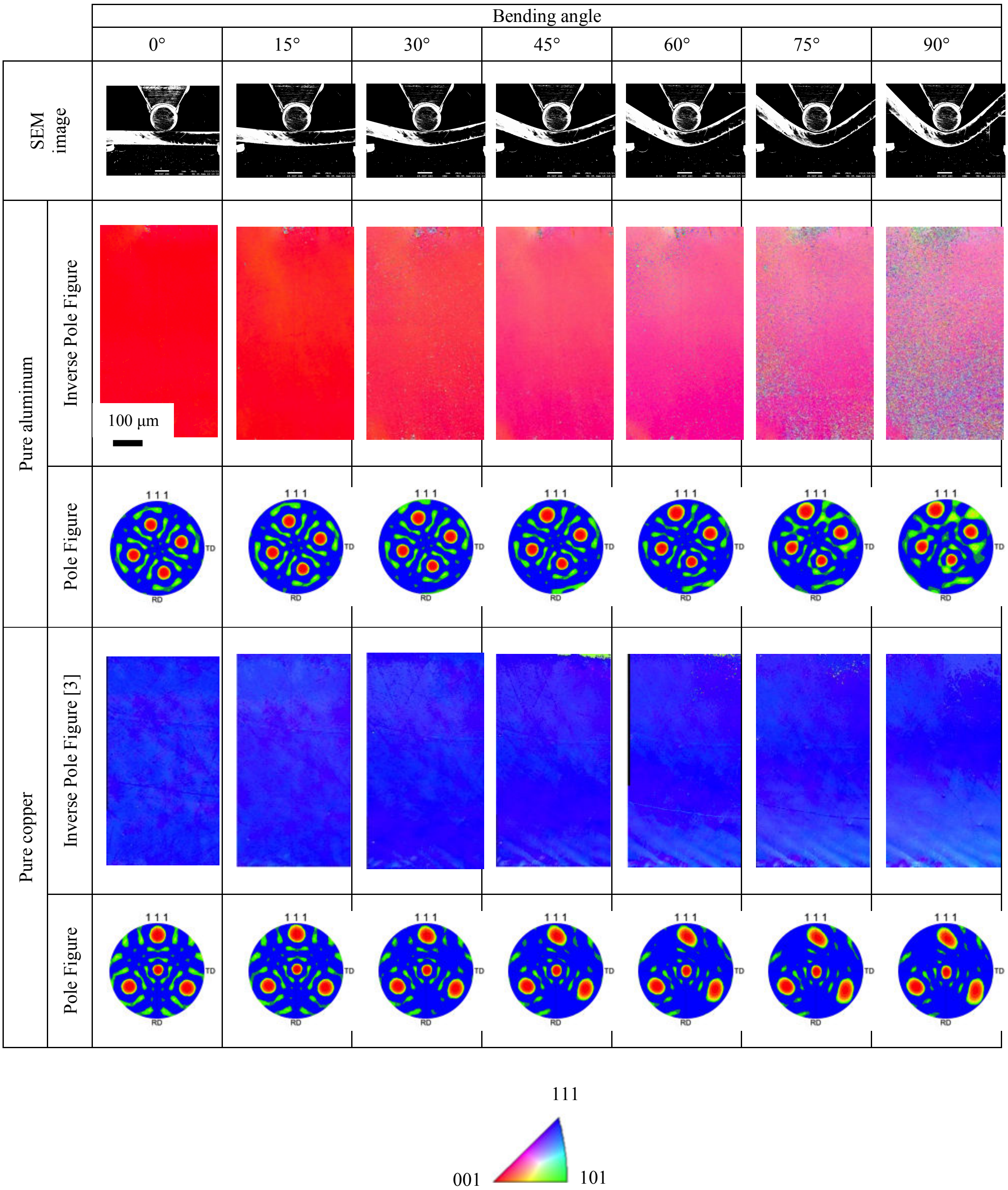
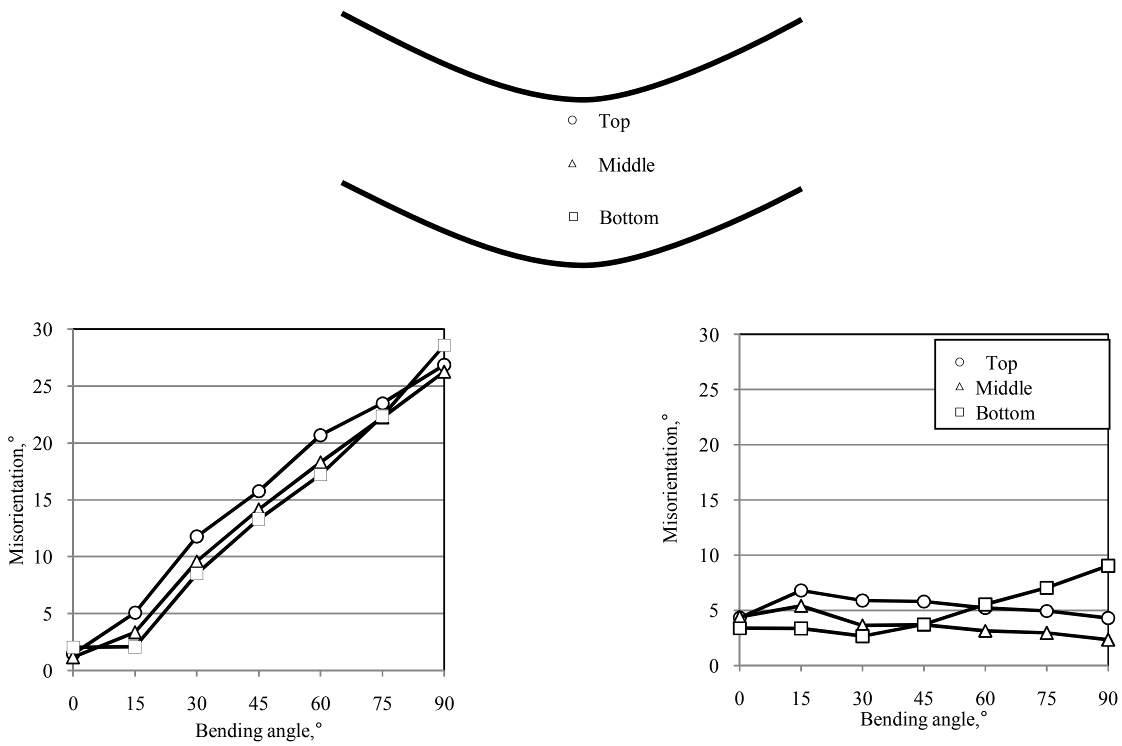


Fig. 3 IPF maps and pole figures after bending



(a) <001> direction in bending for aluminum single crystal.

(b) <101> direction in bending for copper single-crystal.

Fig. 4 Changes of crystallographic orientation.

Pure aluminum was collected to the specimen in the Cube orientation surface. Pure copper has ND // {110}, TD // {111}, RD // {110} directions to produce the bending specimen. Wet polishing was performed using an emery paper by buffing from colloidal silica and Al_2O_3 particles in the polishing of the specimen.

Use of a bending device of TSL Solutions Co., Ltd. is presented in Fig. 2 (a). While bending pure materials textures were observed bending using SEM as shown in Fig. 2 (b). The bending angle was measured at intervals of 15° from 0° to 90°. The EBSD method was used for measuring the crystal orientation, measured the pole figure, and invers pole figure (IPF) maps.

III. Experimental Results and Discussion

The pole figure and IPF map in the angles between materials are depicted in Fig. 3. For the pure aluminum, the crystal orientation was changed from the top. The crystal orientation was changed throughout the entire thickness of the 90 ° bend. As the pole figure shows, the crystal orientation was rotated around the TD axis. For the pure copper, a change in crystal orientation was observed at the bottom of the plate thickness from a 45° bend; the 90° bend was complete. The crystal orientation is shown to be rotated around the <111> axis in the pole figure.

Crystal misorientation in the bending angle of aluminum and copper is portrayed in Figs. 4 (a) and (b). Crystal misorientation was changed greatly at all sites of the thickness used in Fig. 4 (a). Crystal misorientation was about 15° from 45°; the crystal orientation was severely altered. Change of the crystallographic orientation for pure copper was less than that of aluminum in Fig. 4. However, for pure copper, a change in crystal misorientation was observed at the bottom of the plate thickness from the 45° bend in Fig. 4 (b). The IPF map depicted in Fig. 3 also shows the point.

Result show that the crystal orientation changes greatly in pure aluminum with a Cube orientation. The crystal orientation at the bottom of the plate thickness was found to be changed in pure copper, as obtained with other orientations. Strengths differed from those of pure aluminum and pure copper, despite being the same f.c.c. material. Only by considering the crystal orientation, Cube orientation can be easily deformed.

IV. Conclusion

For this study, observations of bending pure aluminum and pure copper were conducted. They showed changes of crystal orientation, although they were the same f.c.c. materials.

(1) For the case of pure aluminum, the crystal orientation changed almost completely from 45° in the entire plate thickness, the crystal orientation rotated around the <111> axis was observed also in the pole figure. The axis orientation rotated from the <001> in the direction of <111>. The crystal orientation was changed at all sites.

(2) For the pure copper, the change of crystallographic

orientation was less than that of aluminum. The crystal orientation of the bottom was rotated greatly around the plate thickness. The axis orientation was rotated only slightly. The crystal orientation was changed at the tension.

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